

# **Using Virtual Simulations In The Design of 21<sup>st</sup> Century Space Science Environments**

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1N-54  
049803

## **Abstract**

Space Technology has been rapidly increasing in the past decade. This can be attributed to the future construction of the International Space Station (ISS). New innovations must constantly be engineered to make ISS the safest, quality, research facility in space. Since space science must often be gathered by crew members, more attention must be geared to the human's safety and comfort. Virtual simulations are now being used to design environments that crew members can live in for long periods of time without harmful effects to their bodies. This paper gives a few examples of the ergonomic design problems that arise on manned space flights, and design solutions that follow NASA's strategic commitment to customer satisfaction. The conclusions show that virtual simulations are a great asset to 21<sup>st</sup> century design.

## **Introduction**

Before we discuss the design project and the details of our virtual simulation approach, it is necessary that we begin by giving a synopsis of the Human Factors (HF) profession. This will help readers understand the concepts behind this fairly new engineering discipline. Many of today's concerns and policies within government, military, and commercial spheres pertain to safety and greater performance of manpower. The design of systems ranging from a control panel in the Space Shuttle to an office desk workstation can be credited to the efforts of the profession of Human Factors Engineering (HFE). The engineering profession is traditionally concerned with making a system or a piece of equipment work, whereas HFE is responsible for making the system or equipment operational by the user. For example, human abilities, human limitations, and human characteristics are fundamental to Human Factor (HF) engineers in "designing tools, machines, tasks, and environments for safe, comfortable and effective human use." [1] Having HF engineers directly involved within a product's development team, is necessary influence to a design from conception to prototype. This is the most effective way this profession can ensure a product or system will effectively accommodate a human user and operator. However, HFE can also be linked with the testing and evaluating of existing equipment or systems for continued improvement.

The terms "human factors" and "ergonomics" have in recent times been associated with each other in advertising. The term ergonomics has its origin from Europe, while the term human factors originates from the United States. Since the terms are so synonymous, in 1993 the Human Factors Society changed its name to the Human Factors and Ergonomics Society. [2] Historically, the first agency or group to recognize the HF profession was the United States Department of Defense, some time between World War I and World War II. The need for HF increased during this time primarily because of the increased use of the automobile and

aircraft in combat. The profession saw its greatest growth during and after World War II. In 1935, the Armed Forces had HF teams relating human dimensions to cockpit design, thus improving crew performance. That challenge is greater today considering both male and female pilots are a part of Air Force flight crews. The HF profession was not limited to government agencies during that time. In 1946, Bell Laboratories assembled a HF group to advise designers on human/system interaction issues. [3] HF groups created in the Department of Defense during and after both world wars have filtered their way into present day NASA, by ensuring that human performance and safety will be optimized during space travel. [2]

HF engineers have clear objectives when modifying a design that involves human interaction. The first objective is product safety, which looks at ways to reduce errors and improve system performance, by defining the roles of the user versus the role of the system, combined with the human thought processes. The second objective is related to basic system operation. The HF engineer determines the best ways to reduce fatigue and physical stress and increase human comfort, ease of use, and user acceptance within a system. The HF engineer must incorporate a pleasing aesthetic appearance, and at the same time reduce operation time and maximize operator efficiency. [1] The third objective of the human factors engineer is product support. Reducing personnel and training requirements while increasing reliability and maintainability are the major issues for product support. The ranking of importance of the objectives categories depends on the discretion of the HF engineer during each particular project assignment.

### **Design Project**

A tool that is greatly helping the HF engineers at NASA meet their objectives is virtual reality (VR) systems. There are two types of VR systems. The first type is a system that completely surrounds the operator. In essence, it places the operator in the virtual environment. The second type, on which this paper will focus, is a system that offers only a window into a virtual environment. [4] VR software typically runs on expensive and highly graphical performance platform workstations. "The traditional acquisition process for new aerospace systems, both civilian and military, entails multiple design iterations, each involving the building and testing of physical prototypes." [5] Physical prototypes, though very helpful in the design process, are very costly, usually take many man-hours to build and are of great value only at a mature stage of a design. Prototypes for space environments have the added boundaries of having to be placed within a neutral buoyancy tank with suited astronauts to simulate tasks being performed in a zero-gravity environment. VR environments now offer the HF engineers at NASA the ability to design by evaluation of simulation-based designs using human-centered performance within the virtual prototypes. Human astronauts of different stature, gender and race, simulating real human movements and constraints, can be placed within a virtual environment in the interior of a virtual aerospace vehicle. Different angles and views can be seen of the vehicle's interior for ideal placement of an astronaut's seat positions, foot and hand restraints, and reach/grab distances for interactive use. Everything within the virtual prototype can be quickly modified to meet the needs of the astronauts for operation and maintenance tasks. Using this platform, VR promises to provide NASA design teams with the ability to attempt new concepts in hardware design and evaluate operational procedures for tasks in shorter periods of time.

The International Space Station is one of the greatest advancements in space science for the 21<sup>st</sup> century. It is for this reason, NASA is going to great lengths to assure that ISS is a success. The latest technology has been applied in all areas of the ISS design. Our Human Engineering and Analysis Team (HEAT) uses virtual reality simulation software packages to give Human Factors Engineering (HFE) design support for future flight hardware aboard the ISS. Since our organization's customers, in many cases, are the crew members, we will focus on the specific tasks involved with designing an ergonomically correct environment for a payload aboard SPACEHAB. HF analysis assures that our customers are receiving the quality they expect. The payload we are concerned with is the Vapor Compression Distillation Flight Experiment (VCD FE), which is an experimental urine processor for the Environmental Control and Life Support System (ECLSS). The VCD urine processor will provide test data for future water recovery systems aboard the ISS. The Human Engineering and Analysis Team (HEAT) is currently working on optimizing the performance of the VCD FE

payload. This urine processor transforms human wastewater into usable water for crew members. This transformation is achieved by going through a process of compressing water vapor, then condensation and evaporation. Rapid rotations in the gravitation-less environment yields a separation of water and waste. Since water has a limited supply in space, it is essential that we find ways to maximize the water resources for humans that undergo extended periods of time in orbit.

VCD will ultimately supply us with much needed test data for future projects such as ECLSS. ECLSS is run by the Water Recovery System (WRS), that is comprised of the Urine Processing Assembly (UPA) and the Water Processing Assembly (WPA). Combined, these components will supply the crew with recycled water from urine, perspiration, condensed humidity and other sources.

## **Design Constraints and Requirements**

The HEAT particularly is concerned with the human interface and operational scenarios of this payload design. We want to make sure that all crew-members are equally capable of performing the tasks that are required to operate the VCD FE hardware. System installation, checkout, wastewater replacements, procedural inputs on the laptop computer, and the periodical maintenance of parts are some of the human interface scenarios that we analyze. All automated operations are irrelevant to our HF analysis.

Manned flights pose numerous design problems that we must resolve. Problems that have surfaced for crewmembers are not being able to: reach tools and gadgets, read labels or task procedures, fasten or unfasten screws and bolts, hear others due to noisy equipment, see under dim lighting, interpret a caution or warning signal, and the list goes on. Since humans vary in stature and ability in many different categories, requirements must be set to accommodate all crew members on a given mission. Height, arm reach distance (reach envelope), strength, visibility, noise range, and interpretation are analyzed and given specific requirements to achieve the comfort and safety of the entire crew.

The VR software that simulates human interaction within a virtual environment for this NASA project is called Transom Jack. This package was initially developed by the University of Pennsylvania and is now marketed and supported by Transom Technologies, Incorporated in Ann Arbor, Michigan. For this project, Jack was run on a Silicon Graphics workstation where 3D CAD files of flight hardware were imported and manipulated to create a virtual environment of the SPACEHAB. The designer can now recreate any equipment, cabinets, or controls in this environment to make it as close as possible to the actual engineering model.

The suggested human's stature is based on percentiles of the average sizes men and women across the world. The chosen range of human figures used within the virtual environment are of a 95<sup>th</sup> percentile Russian male and a 5<sup>th</sup> percentile Japanese female. (See Figure 1) To show how we use these percentiles to design flight environments; we will take a look at the design requirements and solutions for the problem concerning the laptop computer placement and the foot restraint location.

There were questions concerning the ideal placement for the laptop computer for the operation of VCD. We wanted to make sure that the laptop was easily accessible to all crew members and did not cause extra stress or strain to their backs by over-exerting themselves to reach the computer. It is known that an extended period of time at the computer may cause problems to the crewmember if it was not placed in the ideal position. The placement of the laptop, however, was contingent upon on location of the foot restraints. These restraints are essential for harnessing the crewmember while he works on tasks directly in front of him. Since the foot restraints are floor mounted loops secured by Velcro or duct tape, they can be easily placed in the ideal location. The VR applications were used, in this case, to decide at what angles and distance away from the payload the foot restraints will be secured. (See Figure 2)

## Design Approach

Jack was chosen for a number of reasons. Jack satisfied the need for analyzing humans in zero-gravity. A crewmember's reach, fit, comfort and vision are easily obtained within the Jack software platform. Jack accurately reflects human joint movements and constraints while providing anthropometric scaling from a database. Jack also has the capability to create a human figure from actual crewmember body measurements. (See Figure 3). HF engineers at NASA can easily evaluate tasks performed in zero-gravity with tools in Jack such as: collision avoidance behaviors, hand/eye coordination, reach path planning and automatic grasping to part contours. With Jack's line-of-sight feature, HF engineers can see what the virtual human figure sees within the virtual environment. This feature helps answer the questions of whether a clear-line-of sight to all components during a maintenance procedure can be obtained from the human's planned location.

A generic Neutral Body Posture (NBP) of a crew member was placed in the Jack environment to recreate the exact atmosphere that crew members will be working in. This exercise was undertaken first by scanning existing illustrations of humans at front, top and side views in the NBP, and correspondingly placing them within the virtual environment on a x, y, and z plane. Next, a human figure was created to match the scale of the illustrations. Using the VR software's interface tools, the human figure was manipulated to match all of the possible body angles of the desired NBP. (See Figure 4) After the human factors analysis is complete, we were able to decide critical design elements for the SPACEHAB environments. Some of these elements included: width, length, height, and angles.

Disadvantages in applying design techniques within VR environments, at present, are the result of the infancy of this new developing technology. The interaction between the HF engineer and VR software packages can present usability limitations. One limitation can be found when the software interface tools do not capture the user's ideas for manipulating virtual environments. As a result, gaps in perception/action in interpretation of the virtual environment can occur. Take for example a problem encountered when trying to put a virtual crewmember in the neutral body posture (NBP). In reality, the body automatically assumes the NBP in space because of the bodies muscle retraction resulting from the absence of gravity. The HF engineer encountered conceptualization problems of the correlation between moving the human's limbs verses the tools provided on the human movement dialog window. The interpretation of the 3D posture of the virtual human to the 2D postures, proved difficult.

Resolving the user's conceptualization challenges of the software's human movement tools, could be accomplished by digitally capturing an astronaut in space using the "A Flock of Birds" product. "A Flock of Birds" is the name of a device fitted to the human body that tracks real world human position and orientation measurement data. This data can be translated into VR environments and applied to VR human figures. Another limitation, the setting of a small sized female could not be accurately postured at the spine to reflect the NBP. This was because body movements could not move separately from one another within the interface tools. Other disadvantages in the incorporation of design techniques within the VR environment are inaccurate CAD file translations. Many man-hours may be required to correct CAD file data that has entered the VR environment in the wrong scale, position, and orientation. Also, viewing a 3D environment on a flat screen can give a HF engineer a false perception of spacing within the VR environment. [5] However, as VR system's user interfaces improve, user conceptualization within the VR environments created will improve.

## Conclusions

The assumptions going into this design project were that all bodies created in the virtual environment were positioned in the zero-gravity neutral body posture as outlined in the NASA-STD-3000 [6] and that the human stature is increased by 3% in the gravitation-less environment. This offset was taken into account when creating the human stature in the virtual environment.

The Jack software was able to give exact measurements with the click of the mouse on the desired point. Therefore, after time-consuming VR formatting, obtaining the actual measurements for placement of the foot restraints and laptop computer was fairly easy. The results that were found are as follows:

- 1.) Foot restraints were to be placed on the floor 2.5 inches from the payload. They were to be at 25 degree angle parallel from the payload to fit the crewmembers NBP foot angle.
- 2.) The distance between foot restraints was to be 14.95 inches, which is the median distance from the two body statures. This distance was measured from the center of each loop. The distance between the male foot loop was 17.4 inches and the distance between the female foot loop was 12.5 inches.
- 3.) The laptop's keyboard mounting base angle was set at a 14 degree angle from the ground plane. The laptop mounting heights were measured from the center of the laptop base's rear panel to the floor.
- 4.) The maximum laptop mounting height for a 95<sup>th</sup>ile male was measured at 41.95 inches, and the minimum laptop mounting height for a 5<sup>th</sup>ile female was 32.82 inches. The ideal laptop mounting height is centered between these 2 numbers.

No matter what the problems are of using VR environments for inputs to design, the advantages greatly outnumber the disadvantages. Cost is cut tremendously, by using computerized models as opposed to wasteful iterations of hardware prototypes. We save money by making all necessary changes to the designs before the prototype has been built. Time can also be saved by discovering usability problems and making the changes before the crew has been trained on the equipment. Finally, safety can be achieved by finding design problems before launch. As a result, project managers, crewmembers and designers are all satisfied with the technological advancements that VR brings to the table. By understanding these concepts and real life applications, we all can agree that virtual simulations are a great asset to 21<sup>st</sup> century design.

## Appendix

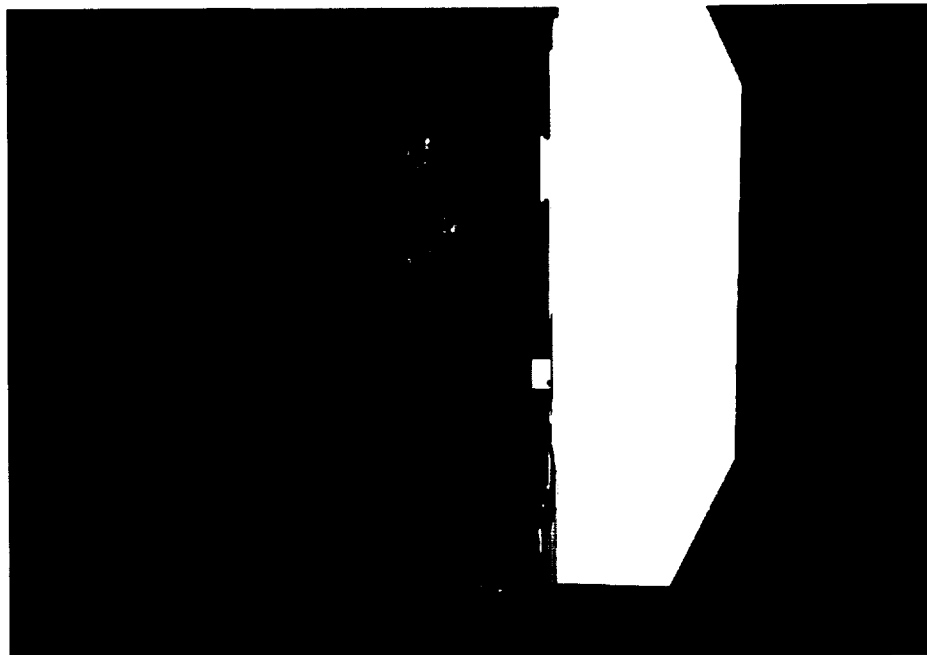
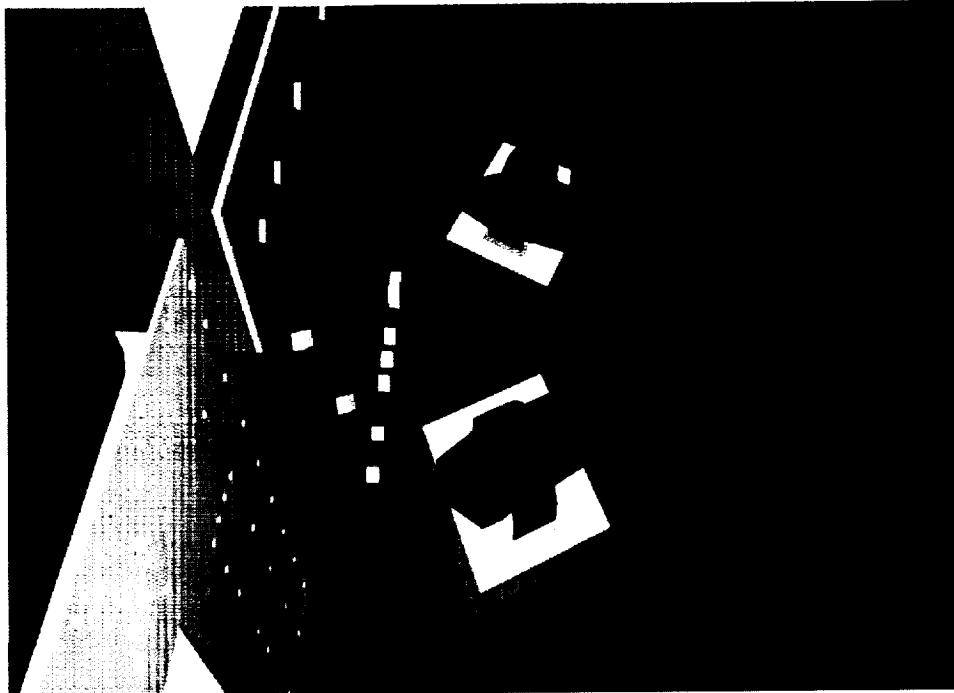


Figure 1: 95<sup>th</sup> percentile male and a 5<sup>th</sup> percentile female.



**Figure 2: Crewmember in virtual foot restraints.**



**Figure 3: Virtual crewmember performing laptop operations.**

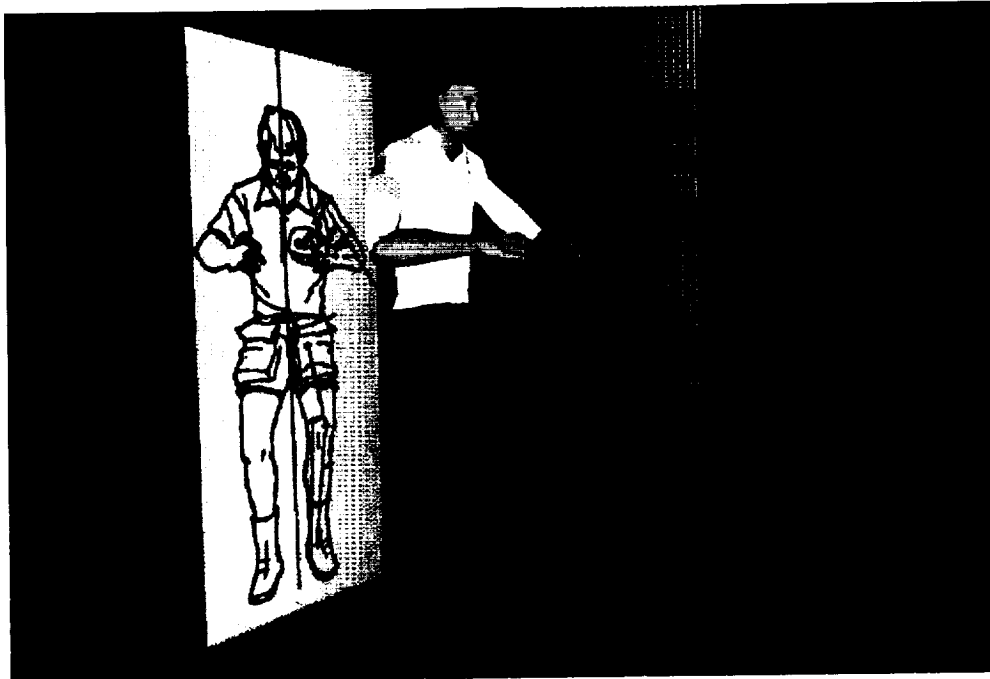


Figure 4: Human figure created to match NBP illustrations.

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### **Biography of Sonya L. Hutchinson**

Sonya L. Hutchinson obtained a B.S. degree of Electrical Engineering in 1994. Since that time, she has been employed by NASA Marshall Space Flight Center. She has worked in numerous divisions within the agency, including the Test Laboratory, Astrionics Laboratory, and Mission Operations Laboratory. Her current job assignments consist of providing human factors design inputs to the Materials Science Research Facility project, and the Portable Fan Assembly. Both of which have future potential to support the International Space Station missions. Her largest task is serving as the ISO 9000 Organization Representative for the Mission Operations Laboratory with duties related to implementing this quality management system across the center.

Mrs. Hutchinson has been an active member of the National Society of Black Engineers (NSBE) since her junior year of college. Some of the positions she has held in NSBE are as follows: PCI Chair and various committees (undergraduate); Secretary and Vice President (North Alabama Alumni Extension), and 1998-1999 Professional Development Chair (Region III Alumni Executive Board). College also sparked a long active membership in the Institute of Electrical Engineers (IEEE). She currently holds the position of Secretary for the Huntsville Section of IEEE. She is also an active member of the Rho Chi Omega chapter of Alpha Kappa Alpha Sorority, Incorporated.

### **Biography of Jeffery R. Alves**

Jeffrey R. Alves of Sigmatech, Incorporated is an Industrial Design contractor in the Mission Operations Laboratory: Human Factors Team at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. In 1994, He was the recipient of the Industrial Designer's Society of America (IDSA) Student Merit Award as an undergraduate in the School of Architecture's Industrial Design program at University of Auburn. While at Auburn as a senior, he won a design competition sponsored by General Times Corporation. This competition focused on the designing of new digital clock time setting technology. His senior thesis for NASA, at MSFC, was to provide conceptual designs focusing on applied ergonomics on micro-gravity science experiment gloveboxes. Currently at NASA, Jeff supports the ECLSS project with Jack analysis and full scale mock-ups that aid in producing the project's operational/maintenance concept document.